PRACTICAL OBSERVATIONS

ON THE GENERATION OF

STATICAL ELECTRICITY

BY THE

ELECTRICAL MACHINE.

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LIEUT. GEORGE W. RAINS, U. S. A.,

Acting Assistant Prof. of Chem., Min. and Geol., U. S. Military Academy.

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Having experienced, at different times, some difficulty in causing an abundant and uniform supply of electricity to be generated, by the apparatus employed, when the state of the air and other circumstances appeared entirely favorable, sufficient inducement was offered to devote a few leisure moments to the study of the causes of failure.

In completing a course of experiments with this object in view, results have been obtained in the excitation of statical electricity, deemed of sufficient value to merit attention. The invention of electrical machines being of such long standing, and the subject having received the attention of so many eminent persons, the writer, with some hesitation, ventures to suggest ideas derived from his own observations. The improvements proposed, however, being few in number and of simple application, he has thought proper to state them, allowing each one who may feel interested, an opportunity of satisfying himself of their utility.

Rubbers.—Commencing with the rubber of the machine, as the supposed principal source of failure, it was proposed to ascertain, first, its mode of action; second, that substance which would be most efficient in its action.

In regard to its mode of action, the questions which presented themselves, were—does it produce electricity by friction, by chemical action, or by friction and chemical action?

Assuming at first that the effect is produced by friction, its mode of action appears to be as follows. The rubber touches the glass at any given moment with a certain number of its parts or points, and does not, therefore, come into contact with the remainder; the friction of these points generates the two electricities,* of which the positive remains with the glass, and the nega-

* It is not intended to assume that electricity is *one or more fluids*, but the ordinary language is used for convenience.

tive with the rubber. At the succeeding moment, the excited parts of the glass have passed opposite to those points of the rubber which do not touch; an inductive action then takes place—the positive electricity of the rubber is repelled, and the negative attracted, by the excited portions of the glass. If the negative electricity produced by the first action, has remained with the rubber, it will then be in such excess at the points in question, as to force itself through the thin intervening stratum of air, and neutralize the corresponding positively excited points of glass.

Hence to remove the negative electricity is of the first importance; and the necessity of being freed from it was perceived in the earliest experiments. Should this be accomplished, however, as perfectly as possible, it is evident that a diminished similar effect would necessarily take place, rendering neutral a quantity of electricity already excited. What has been observed of the situation of the points of the glass and rubber, at the first and second consecutive moments of action, evidently continues during the entire period of operation.

From what has preceded, two primary objects are to be attained: first, to determine the best method of disposing of the negative electricity of the rubber; second, to obviate the injurious effects of those of its parts not in contact with the glass.

To attain the first object, it naturally suggests itself to conduct it off by forming a communication with a conductor between the rubber and earth; and consequently, the directions given, and carried out in the construction of the best electrical machines, have been, to form a metallic connection with the *back* of the rubber, and the surrounding conducting objects. The idea appears not to have occurred, that such communication should be made with the metallic *face*, in place of the back of the rubber. The cushions being made of non-conducting materials, as silk or leather, stuffed with similar substances, the faces of the rubbers are insulated, and the negative electricity is prevented from escaping freely. This insulation is so complete in some rubbers, that with a twelve-inch plate machine scarcely the smallest quantity of electricity could be obtained, until the amalgam faces of the cushions were connected by a wire with the floor, when its amount was suddenly and greatly increased. It has been interesting to observe the numerous near approximations to this result, which, however simple, appears not to have been exactly hitherto attained;—the nearest approach, probably, being the suggestions to stuff the rubbers with elastic fragments of metal,* and the proposition to moisten their interior substance.†

Electrical excitation, in all descriptions of apparatus made use of for that purpose, will be increased by adopting the preceding suggestion. Should the analgam faces of the rubbers be connected with the exterior coating of a Leyden jar, in the act of being charged, the effect would be much more satisfactory—the positive electricity of the coating neutralizing the negative of the rubbers.

The first object having been thus obtained, it remains to pass to the second, viz. to obviate the injurious action of those parts of the rubber not in contact with the glass. For this purpose, it is plain that if a non-conducting substance be interposed between them and the excited glass, the desired result will be obtained; and the question resolves itself into the proper manner of applying the best substance. If an oxidizable metal or amalgam be employed, the oxide which is formed will answer this purpose itself, to a certain extent, as the oxides of the metals are imperfect conductors. For this purpose the oxygen of the air is of service. The prominent points in such cases will be kept bright by the rubbing of the glass. The oxides thus formed, continue to increase in most cases, particularly with the amalgams, and ultimately fill up the intervals; then sustaining the pressure of the glass, all farther action of the exciting points of the amalgam ceases: in such cases, the surfaces of the amalgam require renewal. The oxides, as will be seen hereafter, are but feeble generators. Tallow, lard, and substances of a similar nature, answer the purpose much better, and hence they were soon discovered to be of service in the earlier researches of electricians. The tallow or lard being spread over the surface, or mixed up with the amalgam, surrounded each exciting point of the rubber with a non-conducting medium, and hence fulfilled the required conditions. As, however, these substances readily combine, mechanically,

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* Am. Jour. Sci. and Arts, Vol. xxiv, p. 256.   † Franklin's Letters.

with the metallic oxides, forming a black, adhesive mass, which collects on the glass, soiling its surface, and is troublesome to remove, bees-wax and shellac were substituted, both of which substances, when properly applied, answer the purpose remarkably well. Neither of them soils the glass, and what is of much importance, they give rubbers permanent in their action.

The question now arises, whether there be not other parts of the rubber, besides those surrounding the exciting points, which may have an injurious effect? That portion which precedes the first exciting points at the entrance of the glass, obviously can do no harm, as the glass is supposed not to be excited when passing in their vicinity; but the case is materially different with the opposite termination of the rubber, which, not being pressed against the glass, is highly injurious—abstracting largely from the electricity previously generated. This has also been observed by electricians, who do not, however, appear to have proposed any substantial remedy; the best, apparently, depends for its success on the *regularity* of the pressure;* and still another plan is liable to the same difficulty.† The silk flap, whose utility appears to have been discovered by accident, and whose real object seems to have escaped attention, has succeeded or failed, as chance regulated its proper or improper application. A certain quantity of electricity is doubtless produced by the silk, in whatever manner it may be applied, and the amount is considerably increased by particles of amalgam which adhere to its surface; but the total quantity thus produced is small compared with that given by the rubber, and a larger amount will be obtained by removing the flap and increasing the pressure, so as to bring as many new points in contact as will equal by their friction that of the silk. Hence the above cannot be its true value, neither *did* its utility appear to depend, principally, on its being an interposed non-conducting obstacle between the excited glass and the molecules of air; but rather, having been fastened to the loose edge of the amalgamated leather, this edge was pressed against the glass by the adhesion of the silk, and thus prevented from diminishing the amount of electricity already evolved. It possesses, also, to some

* Partington's Nat. Phil., p. 151. † Nicholson, Phil. Trans., 1789.

extent, the power of preventing the electricity of the surface of the glass from being drawn off or neutralized by surrounding objects. In modern machines, the rubbers are hair-stuffed cushions without the loose leather, and the flap is of varnished silk, which is so arranged, in some plate machines, as not to touch the glass. The first and principal advantage of the silk is thus lost, but the second more certainly obtained.

From what has been stated, it appears to be important to cause that edge of the rubber which the glass last leaves in its revolutions, and which is covered with amalgam, to press constantly, and firmly against its surface. This is best secured by making use of a leather strip, covered with the amalgam, whose edge in question shall be firmly pressed between the glass and rubber, and which is consequently narrower than the latter. The idea now suggests itself, that in thus contracting the rubbing surface, its action may be lessened; hence, the proper dimensions for the rubber are next to be determined. To solve this proposition, requires a further investigation into the phenomena of excitation.

Statical electricity has been assumed to be produced by friction, and hence the result of molecular disturbance. Taking one of the exciting points of the rubber, resting on a corresponding portion of the glass surface; suppose such portion of the glass to move through an indefinitely small space; molecular disturbance will then be produced, both in the exciting point of the rubber and in the corresponding portion of glass surface; by hypothesis, the molecular vibration of the rubber producing negative, and that of the glass, positive electricity, each within itself. If it be supposed that the portion of the surface of the glass, in this indefinitely small movement, has continued in contact with the exciting point of the rubber, then the two electricities, respectively generated in each, will combine or interfere, and a neutral state will be the result whilst such contact continues. But should this portion of glass in its further movement pass beyond the exciting point, its molecular vibration continuing for a certain period, will evolve an additional quantity of positive electricity, which will remain after the molecular vibration has ceased; and this portion of glass will be electrically excited. Should the movement be still further continued, and this excited part brought into contact with the consecutive exciting point of the rubber, its electricity will, by the influence of this point, be nearly if not entirely neutralized. For otherwise it is difficult, if not impossible, to conceive of the evolution and absolute contact of the two electricities, at such point, without combining or interfering.

This view of the subject being taken, it follows, that only the last exciting points of the rubber produce the effective result. This, on first appearance, is a startling conclusion, as it apparently reduces the rubber to a mathematical line; on examination, however, this is found not to be the case; there must be a certain number of these last exciting points, in each of several consecutive parallel lines, as the points necessarily have spaces between themselves; hence a portion of electricity excited on the glass may pass between several, before it emerges entirely from the rubber. It follows, therefore, that a certain breadth of rubber is necessary, although it must be comparatively small. With rubbers, properly constructed, as will be described hereafter, the maximum effect for the larger machines, was produced by rubbers *one fourth of an inch* in breadth; and for the smaller, *one eighth of an inch;* the smaller rubbers having generally a greater pressure.

To determine the above, as well as to ascertain and confirm all other results given in this paper, a numerous set of experiments was instituted, by means, principally, of three machines. One was a glass plate of 12 inches, previously alluded to; one a cylinder of 10 inches diameter and 15 inches long; and lastly a large and beautiful instrument of 38 inches plate, manufactured in Paris. To measure *accurately* the quantity of electricity in each case, one of those admirable galvanometers of 3000 turns of wire, constructed by M. Goujon of the Polytechnic School, Paris, was employed; the amalgam of the rubbers being connected, by means of a copper wire, with one extremity of the coil, the other extremity communicating with the prime conductor, by means of a glass tube containing water, having a wire inserted in each end. The maximum *permanent* deflection of the needle by the 12 inch plate was 16°.

Having thus attained, satisfactorily, the two objects proposed, the discussion will be taken up on the questions first suggested, viz. is statical electricity produced by friction, by chemical action, or by friction and chemical action? The solution of the first two solves the third. To this branch of the subject, it was not considered necessary to devote much attention; for the results obtained by others, superior to the writer in abilities, have decided quite conclusively, that chemical action does not produce the excitement of the electrical machine. Indeed it is difficult to conceive, how ordinary chemical action in the amalgam of the rubbers, can influence the generation of electricity, except in the single case previously mentioned. For if it be supposed, that the surface of the amalgam is made up of numerous small galvanic circles, as is doubtless the case, the air acting, possibly in conjunction with its watery vapor, as the exciting medium; no action could be produced, unless such circles, either singly or collectively, were closed. Under the improbable supposition, that parts of the glass acted as conductors to complete such circles, it would be contrary to all analogy to suppose, that in their movement, they carry off a portion of such current. Neither can it be supposed, that it acts by inductive influence; as in such case, the induced electricity would be of a tension, so extremely low, as not to be apppreciable.

In order, nevertheless, to satisfy any existing doubt, a tube electrical machine was constructed,* whose piston performed the part of a rubber; and the apparatus arranged, so as to admit of being filled with different gases. It was thus found that air, oxygen, nitrogen, and carbonic acid gases, when thoroughly dry (and a vacuum) produced nearly the same amount of electrical action, when the same oxidizable or non-oxidizable rubbers were employed; hence this result coincides with that obtained by others.† The conclusion is therefore adopted, that the electrical machine produces its effect entirely by friction.

The second branch of the subject will now be examined, viz. to ascertain what substance is most effective, in generating electricity by friction. In the endeavor to attain this point, numer-

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* American Journal of Science and Arts, Vol. xxvi, page 111.

† Dans la production de l'éléctricité par frottement, l'action de l'air sur les enduits, plus ou moins oxidables des frottoirs, ne parait exercer aucune influence sur les effets électriques qui eu resultent.—*Peclet's Memoirs.*

ous experiments were made with various substances: a list of some of them is given, arranged according to their effective actions.

1. Bisulphuret of Tin and amalgam.
2. Common Amalgam.
3. Pure Mercury.
4. Bisulphuret of Tin.
5. Tin foil.
6. Zinc filings, (fine.)
7. Copper filings, (fine.)
8. Silver.
9. Gold.
10. Platina.
11. Lead.
12. Caoutchouc.
13. Silk.
14. Paper.
15. Leather, (soft.)
16. Woolen.
17. Plumbago.
18. Iron filings.
19. Antimony.
20. Bismuth.
21. Galena.
22. Talc.
23. Chromate of Iron.
24. Protoxide of Copper.
25. Protosulphuret of Mercury.
26. Chromate of Lead.
27. Protoxide of Bismuth.
28. Peroxide of Manganese.
29. Peroxide of Mercury.
30. Protoxide of Zinc.
31. Protoxide of Mercury.
32. Protoxide of Tin.
33. Shellac.
34. Wax, (no action.)
35. Tallow, "
36. Lard, "
37. Bisulphuret of Mercury with lime, gives negative electricity.

From the preceding, it appears that bisulphuret of tin rubbed over a surface of amalgam, containing but little mercury, is the most efficient of all substances employed; it is, however, inferior in value to the common amalgam, on account of its transient action, requiring frequent renewal; and the quantity of electricity evolved, soon being but little more than that capable of being produced by the amalgam itself. The amalgam, in case the sulphuret is employed, acts principally, by serving as a metallic communication to convey off the negative electricity, as rapidly as generated. Tin or copper filings answer the same purpose, nearly as well as the amalgam.

Hence the common amalgam has been selected, as the most suitable material, on account of the quantity of electricity produced, as well as its ease of application; and, when properly applied, the valuable steadiness of its action. Its composition is but of little importance, equal parts, by weight, of zinc, tin, and mercury, answering every purpose. The zinc and tin are to be melted together, the mercury then added, and the melted mass poured into a wooden box, and agitated violently until cool; then it is to be still further reduced to a fine powder, by being rubbed in a mortar. The various results obtained by different electricians, each recommending a new proportion of ingredients, appear to have been caused by the different conducting powers of the cushions of the rubbers employed; they having failed, probably, in each case to connect the metallic faces with the earth.

It will be observed that the oxides of zinc, tin and mercury, yield but a small comparative quantity of electricity; hence the necessity of frequently renewing the amalgam of the rubbers, constructed after the ordinary method. The combination of mercury with the common metals, being rapidly oxidized by reason of the galvanic action, shows the reason why "amalgams containing much mercury are of transient and variable action."*

It is probable that pure mercury, if it were possible to apply it, so as to cause as much friction between its particles and the surface of glass as takes place with other metals, would surpass all other substances in its effective capabilities. This, however, is impossible as long as it continues fluid, on account of the mobility of its particles; and this mobility constitutes its chief value, by allowing a more perfect contact with the glass; hence its maximum effect can be approximated to, only by rendering it semifluid, in forming an amalgam.

The number of rubbers to be employed demands some attention, and at the same time the action of the double rubbers, of the plate machines, will be examined. Theoretically, the number of rubbers is unlimited; for if one produces a certain effect, six would produce six times that effect, if the electricity be removed as rapidly as evolved; but in practice, the number is necessarily limited, and this limit depends, collaterally, on the size of the plate or cylinder, and the convenience of construction. Cylinder machines have but one rubber, which arrangement may have had its origin, in the larger machines, merely from the

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* Singer's Treatise on Electricity, page 52.

slightly increased difficulty of construction. This arrangement necessarily lessens their power one half.

Plate machines have generally two pairs of rubbers, or four in all; in large plates, this number might be increased to three or four pairs, with corresponding increase of power; but the labor of working the machine would increase in the same ratio; which, in this kind of machines, is a material circumstance. However, with rubbers constructed after a manner to be described, the labor caused by two rubbers, is but little greater than that caused by one, of the common construction.

The action of double rubbers will now be discussed. A single rubber evolves a certain quantity of electricity; one surface of the plate being thus excited, the inductive influence causes a certain amount of positive electricity to become free on the opposite face; which acts also by its induction on that of the opposite surface, and increases its amount; and this action and reaction between the surfaces, continue until an equilibrium is established; the result being, that the original electricity generated, is nearly doubled in its amount. If in this condition, the positive induced electricity of the second surface be removed, it will leave the corresponding quantity of negative electricity on this surface of the glass, which will neutralize the opposite positive surface; and nearly all signs of excitation, on such surface, will consequently cease. By continuing this process, the second surface of the glass gradually ceases to give off electricity; and the quantity generated on the first surface, not being increased by induction, becomes comparatively feeble in its action. The plate has now become charged, in a manner similar to that in a Leyden jar; and if removed and placed on a ring of metal, a corresponding ring being then placed upon it, and opposite to the first, by forming a connection between the two, a strong discharge will take place, and the plate resumes its first condition.

From the preceding, the following conclusions are drawn: 1st, the quantity of electricity generated by the rubber, has its amount nearly doubled by inductive action; 2d, to maintain this increased effect, it is necessary that the induced electricity of the second surface be allowed to remain on that surface. The inductive action being a decreasing function of the distance, it follows, that the thinner the glass, the greater will be the effect; which shows the value of the first conclusion. From the second, it appears, that if a cylinder have a damp interior surface, its effective action will be much diminished; all cylinders should, therefore, have their interior surface perfectly dried, and then be sealed up air tight. If varnished with shellac, which has not been colored by the addition of any other substance, the cylinder, after having been once dried, may remain open without material injury to its generating powers.

The machine being in action with one rubber, it will be supposed that a similar one may be arranged to the second surface of the glass, and diametrically opposite to the first rubber. A certain quantity of positive electricity being generated by the second rubber, it will find itself in contact, and will unite with, the similar electricity induced on that surface of the glass, by the action of the first rubber. Hence the amount on this surface will be much increased; and this additional quantity, acting inductively on the first surface, will likewise increase its excitation; the final result being, that the electricity produced by the rubbers, on each surface of glass, is nearly doubled by inductive influence.

It may at first appear, that by arranging points to each surface of the glass, nearly four times the quantity evolved by one rubber might be collected; on a closer examination, however, it will appear that but little more than one half of this amount can be rendered available; for as soon as the free electricity of one surface is removed, that of the other, to a great extent, becomes necessarily neutralized. The plate acquiring a charge, similar to that produced in the experiment of the single rubber, although to a much less extent; and as the plate revolves, passing between the connected metallic faces of the rubbers, this small charge is neutralized.

It has been so far assumed, that the rubbers were placed diametrically opposite; allowing one to retain its situation, the other will be supposed to change its position. A certain quantity of induced positive electricity being evolved on the second surface of the glass, by the action of the first rubber as already discussed; this passes with the glass surface in its revolution, to the metallic face of the second rubber, where it necessarily becomes absorbed by the negative electricity of that rubber, and the free positive electricity, generated by the first rubber on the first surface, is thus, to a great extent, rendered neutral. If the metallic faces of the two rubbers be in connection, as is the supposition, the glass surfaces will thus be brought back nearly to their primitive state, and the product of the action of the first rubber ceases almost entirely to exist.

It follows from this, that it is important that the rubbers be placed opposite to each other; a slight variation is not, however, very perceptible, by reason of the vibrating molecules of the glass, continuing to produce positive electricity, after passing to a certain distance the exciting points of the rubber. That this is a correct hypothesis may be shown by the following experiment: let the back of the hand be held near the second surface of the glass plate of the machine; on rubbing the opposite surface with a piece of silk, every motion of the rubber, will be distinctly and *instantly* perceived.

Hence, if the electricity of the surfaces ceases to be generated, when the portions of glass pass beyond the exciting points of the rubbers, it follows, that if one of the rubbers be somewhat in advance of the other, the electricity induced by the remaining rubber, will be mostly absorbed, and the practical action of this rubber destroyed.

The length of the rubbers will now be determined. In cylinder machines, the rubbers should extend so as to rub the entire exposed surface of glass; the ordinary practice of limiting their length to a portion of the surface, appears to be deficient in principle. For, let it be supposed that such is the case; then those parts of the exposed glass surface, not subjected to the rubbing action, hence not yielding electricity, must conduct off a small quantity of that produced elsewhere. But should the rubbers extend to the axis, an additional quantity will be evolved, and if the axis abstract a portion, on account of its proximity, it will be but a small part of this additional quantity. It cannot be supposed, that in exciting those portions of the glass near the axis, the glass itself becomes a better conductor.

It is important that the elements of the glass, subjected to the action of the rubbers, be as long as possible; for the glass surface may be considered as composed of an indefinite number of consecutive portions, and as each one of these portions, when excited, acts inductively on those around it, it follows, that the greater the number excited at the same time, the greater must be the reciprocal inductive influence. Hence large machines, when under the same circumstances, must give electricity of a higher tension, than that produced by smaller machines.

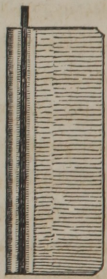
Having thus discussed the principles of action, of the various parts of the rubber, it remains to apply them practically. To obtain the narrow strip of rubber, requires the following process: being provided with a strip of common amalgamated leather, subject it to strong pressure, in order to render the surface flat and smooth; it is then to be rubbed with a clean cloth, to remove any excess of lard or tallow, if such substances be employed;* which must still further be removed from the exciting points, by rubbing the amalgam with a piece of smooth leather dipped into mercury, to which a few particles will adhere; this not only cleans the exciting points, but enlarges their extent.

If the amalgam be now applied to the glass with pressure, those portions of the surface still covered with the lard or tallow, might come into contact at some points with the surface, and produce a detrimental effect; to avoid this, reduce some plumbago (black lead) to a fine powder, which is to be rubbed over the surface of the amalgam, and by adhering to such portions will render them excitable points. It also permits greater pressure for the same amount of friction; and thus the surface is brought more intimately into contact with the glass. From the leather prepared as above described, a strip one fourth of an inch broad, and somewhat longer than the rubber, is to be cut; carefully avoiding to break up the amalgam at the edges, which may be accomplished by covering it with pasteboard and cutting through both substances.

The rubber proper being prepared as above directed, it remains to apply it to the cushion, which, to avoid unnecessary resistance,

* Wax and shellac, as previously stated, may be used with advantage, but they require more care in the manipulation.

should be *three quarters of an inch* or *one inch* in breadth, and this last dimension should not be exceeded in the largest machines. The cushions should be made quite firm, and not stuffed with hair, as that does not allow them to offer sufficient resistance; they should be as perfect non-conductors as possible; the backs of the cushions should be of glass or well-baked wood, in order to prevent the cushion from abstracting a portion of the electricity generated by the rubber. A piece of smooth white leather, about three times the breadth of the cushion, should be fastened by one of its edges to the glass or wooden back of the rubber, and passing over the face of the cushion, will thus be pressed against the glass, the remaining edge being loose. This flap of leather should not be very thin, otherwise there will be a useless adhesion to the glass, increasing the amount of friction unnecessarily; it should be kept *perfectly dry*, as the entire action of the machine, be it ever so powerful, will be destroyed should it become damp on the surface opposed to the glass. To this leather flap, and opposite to the centre line of the cushion, fasten the strip of amalgamated leather by means of a little warm bees-wax; the face of the leather will then exhibit the appearance as shown by the adjoining figure: the projecting end of the rubber proper being left, for the purpose of forming a metallic comnication between it and the exterior coating of a Leyden jar, or with the earth.



To obtain the *maximum* effect, those portions of the leather flap on each side of the amalgam strip, which are pressed against the glass by the cushion, should be touched with a little bisulphuret of tin, which, in the larger machines, will be found to increase powerfully the action; it requires to be renewed, however, every twenty minutes, whilst the machine is being worked; at each of which renewals, the amalgam should be wiped clean, as the sulphuret of mercury, which may be formed, is detrimental in its action. It may be well to observe, in this place, that the glass should be oiled and *wiped clean* before a course of experiments, to prevent its surface from attracting moisture.

The rubber being finished, it must be thoroughly dried to expel any moisture, before being applied to the machine. The ordinary degree of firm pressure, employed in the common-sized machines turned by means of a crank, has been found to produce nearly the maximum degree of excitement; any increase of pressure above this limit, although generally followed by an increased quantity of electricity, is inexpedient, as the additional amount thus evolved, does not compare with the increase of friction; between zero of pressure and this limit, however, the quantity generated is directly proportional to the friction or pressure.

Large plate machines, as will be seen hereafter, admit of less pressure on equal surfaces than cylinders, and consequently are less effective, as the limit above alluded to is not attained.

Plates and Cylinders.—It is now proposed to examine into the comparative qualities of plates and cylinders, in order to determine their relative values as electrical generators.

If an unpolished glass surface be employed, with an amalgam rubber, the electricity generated on the glass will be negative; if it be partly rough and partly polished, the rough parts will give out negative, and the polished positive electricity; if equal in extent, they will neutralize each other's action, and no effective result will be obtained. As the polished surface increases in extent, the rough surface decreasing in the same ratio, the positive electricity acquiring the ascendancy, will increase in quantity until the glass becomes entirely polished, when its intensity will be at a maximum. It follows from this, that the fineness of the polish is a necessary qualification. Inequalities in the surface lessen the effect, by reason of the depressions not being acted upon properly by the rubber; hence the surface should be ground smooth before polishing. The glass should be kept perfectly clean; as any substance adhering to its surface would cause the rubber to act on that in place of the glass, and by hypothesis, a diminished result would be obtained. Should such substance be taken from the rubber, it carries with it a portion of its negative electricity, thus neutralizing a portion of the positive surface.*

* Que lorsque l'un des corps soumis a l'expérience est entamé par l'autre, celui-ci, outre, l'électricité qui lui est propre, prend encore, avec la petite couche mince de la substance qu'il enleve, une portion d'électricité propre à cette dernière; de sorte que la sienne se trouvant modifieé, peutêtre positive, nulle ou négative.—*M. Becquerel, Vol. II, p.* 122.

From what precedes it appears, that plates have the advantage of admitting a finer polish and more uniform surface than cylinders; which latter, however, are usually thinner, and therefore the inductive action is stronger. It will be supposed that the advantages of each are in these respects balanced; it remains to compare their powers. For this purpose, a plate of thirty six inches diameter, with four rubbers twelve inches long each, will be compared to a cylinder of twelve inches diameter, and eighteen inches long, with *two* rubbers eighteen inches long each. As the velocity of the portions of the glass passing under the rubbers is an increasing function of their respective distances from the axis of motion, the velocity of the circumference of that circle, which touches the centres of the cushions, will be taken for the mean; and this, multiplied into the total length of rubber, will represent the amount of glass surface subjected to the rubbing action for one revolution. Hence,

Inches.

(37·6992)48 = 1809·5616 for one half revolution of the plate.

(37·6992)36 = 1357·1712 for one revolution of the cylinder.

It is assumed that the amount of force expended in each machine for each unit of time is equal; hence but one half of a revolution of the plate is considered; for the diameter of its mean circle of resistance being twice the diameter of the cylinder, it follows that the plate will make but one half of a revolution, whilst the cylinder performs one entire revolution. Friction being directly proportional to pressure, it is evident that the sum of the pressures in each machine must be equal: hence the same amount of pressure is exerted on forty eight inches of rubber in one case as is applied to thirty six inches in the other; an inch of each is then pressed in the inverse ratio of these numbers, or as 3 to 4. But by hypothesis, the greater pressure produces the maximum effect; hence each inch of the plate rubbers does not exert its greatest action; and as it has been assumed, that up to the maximum pressure for the same extent of surface the disengagement of electricity is directly proportional to the friction, it follows that the quantity given out by each inch of the rubbers of the plate, is to the quantity given out by each inch of the rubbers of the cylinder, as 3 to 4. But each of the rubbers of the same machine produces, by hypothesis, an equal effect on each equal portion of glass surface subjected to its action; hence is obtained, for the total effective action for a unit of time of each machine, as follows:

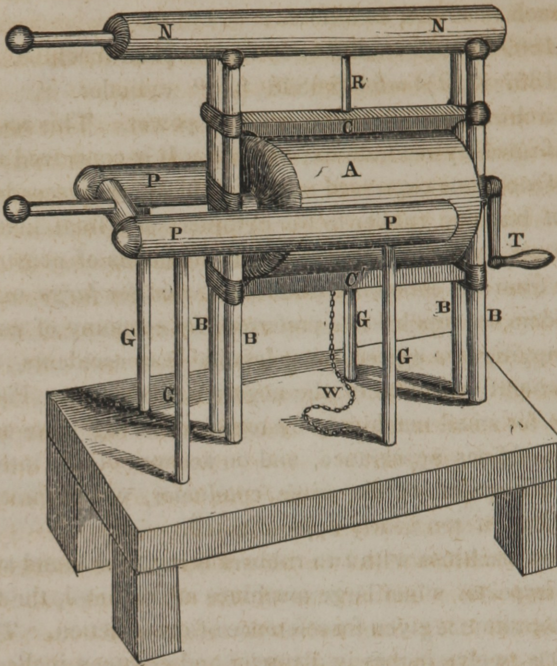
(1809·5616)3 = 5428·6848 for the plate machine.
(1357·1712)4 = 5428·6848 " " cylinder "

The machines are therefore equal in power. This result has been confirmed by accurate experiment. It is conceived that the variety of opinions expressed on this subject has proceeded from the use of but one rubber to the cylinder, and from inattention to the proper method of carrying out the details of construction. It results from the foregoing discussion, that for *large* machines the cylinders are much to be preferred, for economy of construction, occupying less space, being less liable to accidents, and for the convenient collection of the negative electricity. Plates are preferable for small machines, by reason of being more compact as well as of finer appearance, and on account of the interfering action of the points of the prime conductor, which emit sparks to the rubbers if too nearly approximated.

Cylinder machines with two rubbers being thus found superior in many respects, when large machines are required, the following representation is given for reference of construction. The *cylinder* (A) is twelve inches in diameter and eighteen inches long; it is supported by two pairs of glass pillars, (B) (B), (B) (B), one and a quarter inches in diameter each, and three feet long; or of one half this length, and joined together at the axis of the cylinder by brass tubes four inches in length; these tubes being connected by a cross piece, furnish supports to the axis which turns between the glass pillars; these are placed one inch apart.

The *rubbers* (C) (C′) have glass backs one inch broad, and one and a half inches deep, and are about two feet long, moving between the glass pillars, which, by means of brass caps or sockets and screws, cause the rubbers to maintain the proper degree of pressure.

The *positive prime conductor* (P) (P), is composed of two branches, one on each side of the cylinder, each of which is four inches in diameter, and three feet long; these are joined at their farther extremities by a cross tube of two inches in diameter, which has a branch one inch in diameter, and six inches long, terminated by a ball two inches in diameter. The cross piece should be movable in the sockets of the prime conductor.



The *negative prime conductor* (N) (N) is four inches in diameter, and three feet six inches long, supported by the two pairs of glass pillars; it is connected to the top rubber by means of a brass rod (R) one half inch in diameter, which is loosely inserted in a hole in the rubber which communicates with the amalgam. The rod can be withdrawn, and by this means the upper conductor becomes insulated from the rubber, and may be connected to the positive prime conductor, of which it will then form a part. The latter conductor is supported by four glass pillars, (G) (G) (G) (G), eighteen inches long each. The amalgam of the lower rubber communicates with a Leyden jar or the table by a chain or wire (W), which also is connected to the upper rubber when the negative electricity is not wanted.* The crank

* By applying a detached row of points communicating with the ground, and near to the glass between (A) and (C), both conductors will be charged at the same time,—one with positive and the other with negative electricity.

(T) gives the motion to the cylinder. The many advantages of a machine arranged in this manner become evident on reflection; it is sufficient in this place to observe, that if made after the manner directed, it will equal in power *two large plate machines* (the diameter of each plate being three feet) constructed after the common method, and using the ordinary rubbers.

Prime Conductors.—Having already extended this paper beyond the original intention, the remainder of the subject will be concisely treated. Prime conductors of the ordinary form should be of such size as to hold on their surfaces electricity of the same tension as that of the glass, without throwing any of it off. "This tension cannot be exceeded."* If of greater size, they are injurious by reason of their increased surface, presenting an increased extent to the conducting action of the air. If of small size, unless spherical, the excess of electricity is rapidly thrown off; in charging an electrical battery, however, they are preferable to those of larger size.

Prime conductors probably have the best form for common purposes when they are composed of two branches, each having a length double that of the cylinder, (or equal to the diameter of the plate,) and a diameter one fourth that of the cylinder, or one tenth that of the plate: connected by a cross piece one half the diameter of the conductors. Brass smoothly gilt is the best ordinary material; it should be neither varnished nor painted, for the sparks break through such coatings, leaving rough points, which are sometimes highly detrimental.†

The only part requiring particular attention on the subject of the prime conductors, is their *points* to receive the electricity of the glass. A common pin is about one inch long and one twentieth of an inch in diameter; let it be supposed that both ends are pointed and covered with little balls of wax; apply it to an excited body; it will receive a certain charge which has a tendency to escape, which tendency, for a unit of surface equal to that of the point of the pin, at the central portions, will be represented by unity. Remove the wax balls; the pin may now be considered a prolate spheroid, whose transverse axis is one inch

* M. Becquerel, Vol. II, p, 205.

† Faraday's Chem. Manip., note by Prof. Mitchell, p. 452.

in length, and its conjugate, one twentieth of an inch. But in such case the tendency to escape at the central portions of the ellipsoid, is to the same effort at the extremities, "as the square of the conjugate axis (1^2) is to the square of the transverse (20^2):"* hence the effort to escape at the point of the pin is represented by 400. Let it be now supposed that the pin retains its point but doubles its own diameter; the proportion will then be as 2^2 to 20^2, or as 1 to 100. Hence by doubling the diameter of the pin, it has diminished the power of its point to one fourth; this shows the importance of having slender points.

The influence of a point depends moreover on the tension of the electricity, and appears to act as follows. From the position at which the point first shows signs of being acted upon, draw a cone of rays tangent to the exciting electrical atmosphere, having the point at the vertex; this cone of influence being formed of neutralizing rays, the intensity of their action, by the laws of induction, depends on the distance of the point from the exciting body. As the point approaches this body the elements of the cone, remaining tangent, diverge until having reached a certain degree of divergency depending on the intensity of the electrical action, they cease to separate; and if the point continue to approach the excited body, the cone will be intersected by this body. These intersections decrease in extent until the point touches the body, when its influence, except for the corresponding point in contact, ceases. For electricity of low tension, the point being that of a common sized needle, the limiting angle of the elements of the cone appears to be about 166°, which, if the point be at one fourth of an inch distant from a plane exciting surface, will intersect such surface in a circle, whose diameter is about four inches. The electricity within the circumference of this circle will be entirely neutralized. It appears therefore that the points of the prime conductor to collect electricity of *low* tension, should be needles, and placed not farther apart than four inches. The electricity on the glass surface on leaving the rubber, being of high tension, soon commences to be acted upon by the points of the conductor; its tension rapidly dimin-

* Murphy's Mathematical Discussions on Electricity, p. 69.

ishes as it approaches the points, and when opposite, entirely ceases. The prime conductor however being insulated, and having acquired a certain degree of tension itself, refuses to accumulate any more electricity of the same or lower tension; the parts of the glass opposite to the points being thus in an excited condition, electricity of higher tension arrives nearer and nearer to the point at each revolution; its inductive action causes the elements of the cone of influence again to diverge, enlarging the area of the intersection. The prime conductor and glass having arrived at the same electrical state, those points which find themselves in the most favorable positions, will receive the electricity having the highest tension, and the remaining points, in place of receiving, will give off electricity to those portions of the glass which may, from any defect, have less tension. It hence appears, that needle points should not be nearer to each other than four inches, to collect electricity of the lowest tension: as this however in most cases is almost instantly increased, five inches would answer a better purpose, in order to diminish the number as much as possible. In charging large batteries, an additional set of movable points might be employed, to be taken off as soon as the tension reached a certain extent. From the discussion of the action of the rubbers in plate machines, it will be concluded, necessarily, that but *one* permanent set of points to each double rubber should be employed, which may be on either side of the plate—a set for each surface being not only useless but injurious.

By applying the suggestions given in this paper to electrical machines of the common construction, it will be found as a general result, that those of the best construction will double their action, and that others will more than quadruple the amounts previously generated.

Thus has the subject of the ordinary excitation of statical electricity been as fully discussed and applied, as the small amount of leisure time at the disposal of the writer would admit; and although necessarily imperfect, it is still confidently believed to contain hints, which if acted on, will richly repay the electrical amateur.